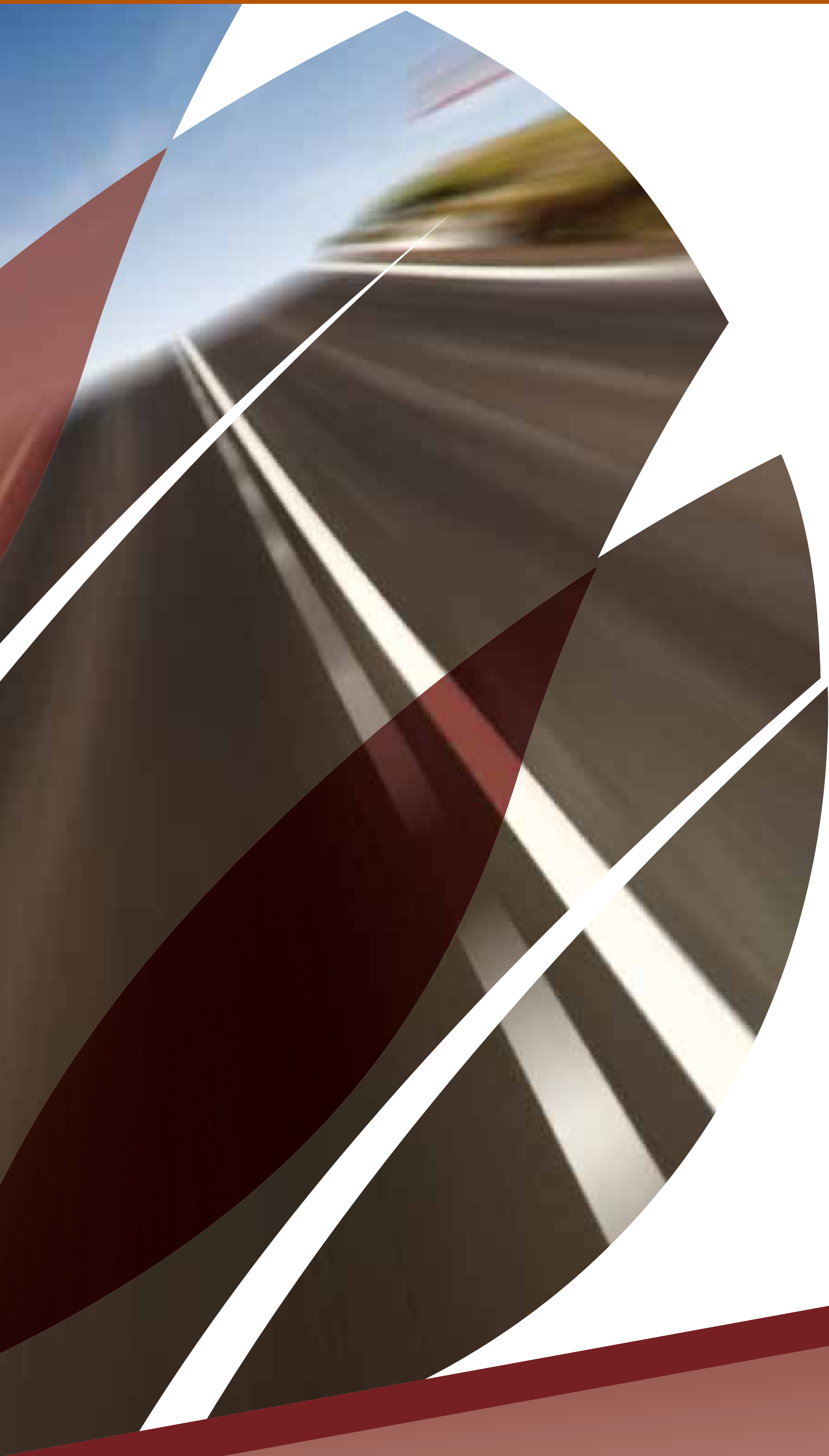

The Future of Roads

Reducing environmental pressures and the management of carbon

A Sustainable Built Environment National Research Centre (SBEnrc) Briefing Report – November 2011
Project 1.3: The Future of Roads – Reducing environmental pressures and the management of carbon

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Synopsis

Although road construction and use provides significant economic and social benefits, its environmental impact is of growing concern. Roads are one of the greatest greenhouse gas contributors, both directly through fossil energy consumed in mining, transporting, earthworks and paving work, plus the emissions from road use by vehicles. Further, according to the Australian Government, when combined with forecast population growth, internal migration and changes in temperature and rainfall, these are expected to increase road maintenance costs. This discussion paper outlines opportunities within the Australian context for reducing environmental and carbon pressure from road building, and provides a framework for considering the potential future pressures that will affect the resilience of roads to the impacts of climate change and oil vulnerability. Seven strategic areas are outlined for further investigation, including a guide to carbon management for road agencies covering planning, funding, procurement, delivery and maintenance of roads.

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1. Introduction

The Future of Roads project is focused on supporting Australian governments and industry to respond to issues and risks related to climate change, availability of natural resources, and issues related to energy — especially oil. As such it is important the program's outputs are relevant and timely. Hence the project team is working in close consultation with government, industry and university stakeholders. Informed by a comprehensive literature review, the research team has evolved the original scope of the project in line with stakeholders' needs and by learning from other similar efforts. This paper outlines the key findings from the literature review, presents results from the stakeholder workshops to provide the core rationale, approach and strategic areas that are being investigated in this project, and provides a short summary of the project in the final section.

2. What have we learned about the future of roads so far?

Road building is inherently an efficient practice that seeks to minimise costs related to construction and maintenance, with a range of considerations given to current and future environmental issues. Such practices include balancing earthworks to optimise cut and fill levels, using local sources to minimise the import of materials, ensuring impacts on the local environment and biodiversity are appropriately managed, optimising pavement thickness for anticipated conditions, and effective scheduling of associated capital expenditure. These practices have enhanced Australia's extensive road infrastructure over the last two decades and will be a key part of road building in the coming decades.

Recent history clearly shows that roads are a cornerstone to economic activity, demonstrated simply by the fact that to deliver a single cup of coffee can require as many as 29 different transport-related activities. However, the basis for the planning, funding, procurement, delivery and maintenance of roads and road infrastructure will need to be reconsidered to respond to a range of emerging factors related to climate change, availability of natural resources, and issues related to energy, especially oil. These factors include predicted resource shortages, increases in energy and natural resources prices, increased costs related to greenhouse gas emissions, changing use and expectations of roads, along with shifting weather patterns and changes to frequency and intensity of weather events.[1] Such trends and factors will lead to a greater imperative to reduce environmental pressures from roads and increase carbon management processes.

A few facts about roads:

- Globally, the distance covered by roads is more than 34 million km,[2] nearly 90 times the distance from the Earth to the Moon. In Australia the road network spans a wide variety of geographic areas and, according to the BITRE in 2009, it extends a distance of some 814,000 km,[3] enough to circle the Australian coastline 31 times.[4]
- The value of road construction in Australia has been estimated at around $17.5 billion a year, and road maintenance costs are estimated to be around $5 billion a year and rising. According to the Australian Government, for example, when combined with population growth and internal migration, changes in temperatures and rainfall are expected to increase road maintenance costs by over 30% by 2100.[5]
- Each kilometre of road constructed requires large quantities of rock, concrete, asphalt and steel to be sourced, transported and placed. A typical two-lane bitumen road with an aggregate base can require up to 25,000 tonnes of material a kilometre, showing why aggregates are the most mined resource in the world.
- The emissions from the mining, transportation, earthworks and paving associated with road construction, as well as emissions from road users, makes it one of the greatest contributors to climate change, some 22% of global carbon dioxide emissions.[6]
- Roads support an automobile industry that employs millions of people and sells a copy of its product every 1.5 seconds.[7] Road infrastructure also supports vehicles that combust 310,000 barrels of oil every day in Australia and emit 17% of Australia's greenhouse gases.[8]

Roads are a vital component of our social and financial systems, providing mobility corridors for people, enabling freight networks to transport food, goods and services, and provide distribution paths for emergency services and disaster relief teams. Climate change is likely to affect road infrastructure and use as climatic conditions become more extreme in many areas of Australia and threaten the viability of essential services and systems that rely on them, leading to calls to reduce greenhouse gas emissions. Furthermore roads contribute significantly to climate change through their construction, maintenance and use.

While efforts are being made to respond to climate change through efforts to mitigate greenhouse gas emissions and adapt to changing climatic conditions, there is an additional challenge for the transport industry and especially roads — that of declining availability of cheap oil. The concept of 'peak oil' is much disputed as it implies there are no alternatives to replace this declining resource; however, there is little doubt, after a review from the International Energy Agency, that the easy and cheap sources of conventional oil have peaked and that from hereon the world will be relying on non-conventional oil, which is much more expensive.[9] In an interview on *Catalyst* on 28 April 2011, the IEA's Chief Economist, Dr Fatih Birol, had this to say:[10]

In 2008 we had a look at 800 oil fields on a field-by-field basis. It is the most detailed study carried out in the world, and we have seen that the decline rate, the decline in the existing fields, are very, very deep ... the existing fields are declining so sharply that in order to stay where we are in terms of production levels, in the next 25 years we have to find and develop four new Saudi Arabias. It is a huge, huge challenge that we continue to underline. And on top of that, this would mean that the world's reliance in terms of oil supply would be on a very few number of countries in the Middle East.

Embedded within these two problems, however, is an opportunity for innovation: to contribute to climate change mitigation efforts through the use of innovative design and technologies, and to develop innovative ways to manage carbon, especially oil. A range of efficiency measures and alternatives to various materials can reduce the environmental impact of road construction, while investments in alternative automobile fuels, increased automobile fuel efficiency, and alternative transport modes and options, can minimise the impact of road users. There may be opportunities for roads to go beyond reducing negative environmental pressures to providing net climate change mitigation benefits.

For example, alternative road base materials may provide opportunities for sequestering carbon, roads may be designed to allow electricity generation through capturing solar or kinetic energy, and transport systems may be designed in ways that encourage multimodal usage and allow a reduction in the area of road needed, creating space for development and public green space. Further, roads may enhance the resilience of human settlements and systems by reducing the risk of, for example, bushfires by acting as a firebreak, or providing mobility during extreme climatic events, such as floods or cyclones. In the face of more frequent natural disasters, such as floods, cyclones and bushfires, roads become a nation's lifeline to affected communities and will need to be able to resist inundation, heat and stress damage.

Understanding how climate change and oil vulnerability will affect Australia will need to underpin the future design of roads so that the services that rely on them remain viable. Hence, key challenges for road designers are to understand the impacts of climate change and to reduce the oil vulnerability of roads. Determining a road's level of susceptibility to the effects of climate change and oil vulnerability, and its ability to adapt to and mitigate these effects, is an important part of investigating the future of roads. Table 1 provides an outline of the impacts of climate change, and oil vulnerability, matched with specific implications for roads and road construction.

Table 1: Impacts of climate change on road infrastructure

Issue	Implication for Roads
Temperature increase and severe droughts	• Increased road maintenance of surface cracking from changing landscape topography caused by evaporation • Maintenance caused by increased wear and tear of road surfaces due to temperature increasing the fragility of the road surface • Increased rehabilitation of road surfaces from surface cracking, warping and asphalt bleeding (flushing)
Increased extreme rainfall events and flooding	• Increased amount of road maintenance caused by potholes being created when water enters the road surface • Increased road rehabilitation because of flooding events affecting large expanses of roadways • Decreased ability for maintenance and rehabilitation to take place because of extreme weather events affecting construction days and access • Road flooding putting pressure on road network and drainage systems
Population increase	• Demand for new road infrastructure and maintenance • Demand for upgrading existing infrastructure
Sea level rise	• Implications of saltwater corrosion of roads because of flooding increasing the water table and sea level rise • Increased storm surge and wave impact on coastal and low-lying coastal areas
Increased cyclones	• Increased debris on roads causing road damage and traffic hazards
Peak oil costs	• Increased costs of road infrastructure and maintenance • Increased cost of fuel and effect on private vehicle use behaviour

Source: Whistler, L. (ongoing) *Masters Thesis*, Queensland University of Technology.

The past decade has seen a focus on the footprint and alignment of roads to minimise ecological disturbance, whereas the coming decade will see a significant focus on managing carbon throughout the planning, funding, procurement, delivery and maintenance stages of road infrastructure.

3. How can the environmental pressures and oil vulnerability due to roads be reduced?

With this context in mind, the literature was reviewed for ways to reduce environmental pressures and oil issues from road building. From the literature review it is clear that across government and industry momentum is increasing to reduce environmental pressures and carbon emissions during road building. There are a number of opportunities throughout the various stages of road and infrastructure development that allow a reduction in these pressures, as outlined in Table 2.

Table 2: Example options for reducing environmental and carbon pressures related to roads

Aggregates processes	Aggregate materials selection
Extraction • Increased fuel efficiency and fuel switching in extractive equipment and plant Crushing • Increased energy efficiency of crushing equipment and techniques, such as considering cutting angles Transportation • Increased fuel efficiency in transportation and distribution vehicles • Options to shift transportation modes, such as from trucks to rail • Consideration of the moisture content of aggregate materials to reduce haul weights Placement • The potential to use saline or non-potable water in road base stabilisation • The use of non-potable water for dust control	Alternative materials • The potential to redirect waste products to replace extracted aggregates, such as: - glass - plastic - flyash - recycled road materials - tyre rubber • The potential for aggregate replacement through in-situ stabilisation, such as: - foamed bitumen - cement blends - geopolymers - red sand - quicklime - lime, slag and fly ash triple blend - alkali activation
Bitumen	**Concrete**
Materials • Opportunities for the use of alternative aggregate materials • Opportunities to innovate bitumen mix design Processes • The use of warm-mix technologies. • The use of cold-mix applications • Innovations in methods and techniques for bitumen placement	Materials • Opportunities for the use of alternative aggregate materials • The use of cement alternatives, including sulfoaluminate cement, magnesium phosphate cement, and aluminosilicate (geopolymer) cement Processes • The potential to store carbon in concrete, in particular magnesium phosphate cements • Innovations in methods and techniques for cement placement

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Source: Whistler, L. (ongoing) *Masters Thesis*, Queensland University of Technology.

There are also a number of emerging innovations that are promising significant reductions in environmental pressures, such as:

- Technological advances at asphalt plants create a 'half-warm mix'[11] reducing emissions and toxic fumes for personnel and construction staff respectively. Innovations in rock-crushing techniques are beginning to reduce the energy required to produce suitable aggregates for pavements and bases.[12, 13]
- In situ stabilisation has been recognised as a key innovation trend for economically reducing the raw aggregate and energy requirements of new roads, especially in regional areas. Industry examples of this emerging field are foamed bitumen (with a trial made by Qld DTMR[14]), and the use of geopolymers, including bauxite and alkali activation technology.[15, 16]
- The industry for recycling of aggregates and concrete continues to grow [17], with state authorities beginning to amend raw aggregate specifications to encourage and support innovative products. The recently released Queensland Main Roads Specification MRS35 – Recycled Materials for Pavements, highlights the growing awareness and is a positive sign that innovation is moving beyond small-scale trials and into mainstream industrial applications.[18]
- A joint research initiative by Curtin University and Alcoa has resulted in the creation of a specification detailing the use of residues (from the production of bauxite) as a practical road base material.[19,20] The investigation also revealed a successful project in Europe demonstrating the reuse potential of bauxite in embankment construction.[21]
- Innovations that sequester carbon are also beginning to emerge, with prototype solutions for concrete and aggregates.[22] For example, the Queensland-developed bio-composite material Carbonlock™ is intended to improve the sustainability of construction materials by using polymers from waste streams that can store carbon.
- Other innovative trials include the use of waste plastic and glass in road construction, supported by the Packaging Stewardship Forum and NSW's Roads and Traffic Authority (RTA).[23]
- The calculation of greenhouse gas emissions tools and energy consumption for road construction is also gaining popularity on projects in Australia by VicRoads[24] and in Europe[25] respectively. For example, the Mickleham Project calculated their emissions in order to offset their carbon footprint by planting 7,500 trees to offset 2,002 tonnes of greenhouse gas for a cost of approximately $25,000.

Like every nation around the globe, Australia is faced with the necessity to upgrade, expand and maintain its road systems and infrastructure. From the literature review and stakeholder engagement for this project, it is clear there is an increasing focus on sustainability innovations, including identifying the effective use and implementation of recycled materials, ameliorating in situ materials, and using industrial by-products. In addition, measurements are increasingly being used to monitor the environmental and carbon performance across a number of factors. Table 3 shows potential measurements to consider with the sustainability of road projects, the results of a brainstorming activity by participants in the stakeholder workshops.

Table 3: Sample metrics for the consideration of the sustainability of roads

Energy/emissions	
The percentage of renewable energy used per km of road constructed The total amount of energy used in construction (direct and indirect) Tonnes of CO_2e emitted during road construction (both direct and indirect). Tonnes of air pollutants emitted during road construction (PM10, VOC, NOx) The percentage of renewable energy used to maintain and operate roads The revenue from energy generation, carbon sequestration per lane-km of road	Level of design for low carbon use (gradients, intersections, albedo) The level of noise generated by final road surface Road surface characteristics post-construction (roughness, temperature) Embodied energy in materials Impact on urban heat island effect Efforts to reduce heat island effect (such as increased tree canopy coverage, surface finishing and materials choice)
Biodiversity	**Ecosystems**
The creation or linking of wildlife corridors The enhancement of existing wildlife corridors and biodiversity hotspots Innovative practices to reduce negative biodiversity impacts Percentage of capital cost invested in practices to reduce negative biodiversity impacts Species count before and after construction Efforts to reduce wildlife deaths from vehicles (including signage, road speed levels, fencing, sonic systems and nature under- or overpasses)	Ha of land revegetation as part of project Ha of land revegetated to offset construction footprint (such as replanting and ecosystem development) Percentage of land revegetation to total construction cost Percentage of capital cost investment in erosion and sediment control measures Percentage of unpaved area revegetated Efforts to reduce potential impacts from noise and dust Level of effective road alignment to avoid endangered environments
Water	
Water efficiency during pavement material mixing and compaction (including trickle system vs. flood mixing, additives in water, orange oil use and Bomag mixing) Distance to non-potable water supply suitable for construction purposes Economic assessment of access to non-potable water vs. potable water sources Percentages of the use of potable, bore and sea water used Risk of impact from sea level rise (measured in distance above sea level and distance from ocean) Economic assessment of the cost per day if road is inundated or damaged by salt water intrusion (road importance factor) Consideration of long-term characteristics of road base when inundated with sea water	Consideration of flood resilience (measured in height above predicted design events) Level of innovation in drainage infrastructure (such as provision for animal habitat and access corridors, and the daylighting streams and natural water courses) Ha of affected watercourse and wetlands Ha of watercourse and wetlands protected or enhanced to offset construction footprint Percentage of watercourse restoration to total construction cost Volume of runoff treated on site via swales and innovative practices Level of retention of original flow patterns, overland flow and water courses

Materials	
Distance imported aggregate travels per kilometre of constructed road Tonnes of materials imported to project Percentage of alternative materials for road base (considering the longevity and security of supply) Percentage of materials recycled (both on and off project) Percentage of project-specific raw-material extraction (adaptive reuse) The use of adaptive reuse or rehabilitation options (considering cost and legacy) Lifespan of pavement (total years and maintenance programs)	Impact on materials longevity from maintenance activities over life Volume of bitumen used (considering potential exposure to oil price increases) Percentage of alternative materials for bitumen (considering the longevity and security of supply) The use of results of innovative trials in materials (in situ stabilisation) The opportunity for innovative materials trials as part of project The level of strategic risk-taking on alternative materials Rehabilitation (costs and community legacy)
Community	**Maintenance**
Options to raise environmental and sustainability awareness in local and wider community as a result of the project Number of ideas submitted and adopted through community engagement Level of participation of community members in project team. Number of entry level labour (i.e. apprenticeships) in project team Level of local knowledge (including professionals, elders, community leaders, etc.) used in project Level of community satisfaction shown by community (during and post-construction) Level of safety of constructed roads (number of 'black spots' per km of road)	Population serviced per lane/km of road constructed Average distance travelled per maintenance task Level of strategic vs. reactive maintenance Total anticipated km travelled for maintenance/lane Cost comparison of the provision of public transport options vs. road investment based on expected patronage Considerations and methods to reduce and manage traffic congestion Consideration of legacy and whole of life social costs and opportunities

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Source: Drawing on the findings of SBEnrc Stakeholder Workshops, hosted by Western Australian Main Roads in Perth on 12 July 2011, and Qld Department of Transport and Main Roads in Brisbane on 9 September 2011, facilitated by Curtin University and QUT.

The literature review to date has identified a growing number of trials of efforts to reduce the environmental and carbon pressures during construction, despite the existence of complex barriers to such projects. For example, such barriers derive from changes to construction techniques (which cause delays to allow re-training and new processes to be developed on site, and require renewal of vocational training, higher education and professional development programs), plus the risks associated with using such options because of their short history of application.

4. What will be the increasing pressures on the 'future of roads'?

As highlighted previously, in the coming decades road agencies will face a range of new challenges — which in many ways will bear little resemblance to the challenges previously faced — and as such will require a number of new approaches. Given that roads typically have a design life of 20 to 40 years, with bridges being designed for up to 100 years, the level of consideration of future trends related to environmental and carbon impacts, economic risks, and social movements associated with roads will have a significant impact on their long-term associated costs and future. With this in mind, this project, supported by a number of Australian state governments, is investigating the likely influences on the future of roads and considering how a strategic response can be informed (see Table 4).

Table 4: Workshop assessment of increasing pressures on the future of roads

Climate change*	Modal shifts to rail and public transport
Rising price of oil*	Biodiversity degradation and collapse
Increased community action*	Loss of agricultural land
Decreasing access to resources*	Increased automation
Population growth*	Waste reduction and harnessing
Increased freight*	Growing middle class
Maintenance costs*	Peaking of food production
Increased community expectations of transport network*	Alternative fuel source
Employment and skill shortages*	Changing world powers
Global financial crisis*	Pressure for intergenerational responsibility
Water scarcity*	The influence of the government
A price on carbon	Decentralisation
Technology innovation	Congestion increases
Rapid urbanisation and densification	Globalised tourism
Increased use of social networking	Health costs and impacts
Increased use of smart phones and applications	Changing lifestyles affecting mobility
Increased frequency and intensity of extreme weather events	New transport paradigms
Growing environmental awareness and cooperation	Short political cycles
	Methods of energy generation

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* Participants were asked to identify the most influential increasing pressures on the future of roads, listed first and designated by a star.

Source: Drawing on the findings of SBEnrc Stakeholder Workshops, hosted by Western Australian Main Roads in Perth on 12 July 2011, and Qld Department of Transport and Main Roads in Brisbane on 09 September 2011, facilitated by Curtin University and QUT.

As part of the provocation to consider the increasing pressures on the future of roads, the participants were provided with a list of the preliminary themes from the Australian Green Infrastructure Council (AGIC) Rating Tool that is being developed, as shown in Table 5.

Table 5: Australian Green Infrastructure Council Rating Tool (preliminary themes)

Purchasing and procurement	Land management
Reporting and responsibilities	Waste management
Making decisions	Functioning ecosystems
Climate change adaptation	Enhanced biodiversity
Knowledge sharing and capacity building	Participatory processes
Value for money	Positive legacy
Economic life	Urban and landscape design
Energy use water	Knowledge sharing
Materials selection and use	Capacity building
Greenhouse gas management	Increased knowledge and applied sustainability and
Discharges to air, land and water	equity

Note: Four sub-categories are yet to be decided and are currently under review.

Source: Australian Green Infrastructure Council [26]

As Table 4 shows, there are a growing number of increasing pressures on the future of roads, some clearly understood and some newly emerging. Considering the impact on roads from such pressures represents a significant challenge and an opportunity for creativity and innovation. The research project seeks to demonstrate that by embracing new technology and innovations effectively and strategically, governments can ensure roads not only minimise their impact on the environment and reduce their carbon and oil pressures[27,28], but also make significant contributions to society and the economy.

Considering climate change as a pressure on the future of roads, the most recent Intergovernmental Panel on Climate Change (IPCC) assessments suggest that *'warming of the climate system is unequivocal'*, and will have significant impacts on the world's cities and infrastructure. Such impacts are increasingly being felt, with Australia experiencing marked declines in regional precipitation levels along the eastern and western coasts in the early parts of the last decade and significant increases in the north.[29] Such changes to precipitation levels will have impacts for roads and will influence soil moisture contents, pavement moisture levels and design life, and design loads on stormwater infrastructure associated with roads.

The environmental, financial and social impacts of climate change represent one of the most pressing global issues, and will directly and indirectly impact current and future road infrastructure. The solutions to such a challenge will need to be dynamic and flexible to successfully navigate the inevitable changes to the environment, society, and the economy. The unprecedented nature of the potential impacts from climate change on roads is such that the existing assessment and planning frameworks are likely to need updating and integrating. Further, the potential for many concurrent pressures and events to compound each other is such that there is an urgency to developing an understanding of the future of roads within these contexts, and using the appropriate tools and frameworks so that road design and construction is resilient and responsive to the future.

Existing efforts to reduce environmental and carbon pressures, to adapt road-building practices to address the threats of climate change and oil vulnerability, are being enhanced by a number of emerging frameworks and rating schemes for infrastructure across the planning, funding, procurement, delivery and maintenance stages in the provision of quality roads. For instance:

- Planning. Roads Australia, the national peak body for the road transport sector, has developed a Sustainability Chapter to emphasise and address sustainability in major road construction projects. This has resulted in a number of non-price-based criteria to rate and rank the overall sustainability of complex road infrastructure projects.[30]
- Funding. Infrastructure Australia has developed a number of tools and assessment procedures related to improving the quality of infrastructure in Australia, including how to reduce the impact on greenhouse gas emissions.
- Procurement. VicRoads has released INVEST (Integrated VicRoads Environmental Sustainability Tool), a tool that can help assess the equality of the sustainability considerations and practices that are included in road construction projects.[31] The tool promotes projects that advance the state of sustainable transport solutions, and requires independent verification of certification. Early outcomes of INVEST have been reported to be the driving and achievement of reductions in greenhouse gas emissions from road construction projects.

- Delivery and maintenance. The Australian Green Infrastructure Council (AGIC) is preparing to release an assessment scheme to the industry in late 2011 that will apply to many types of infrastructure, including roads. Demonstration trials are under way, including two in WA by Main Roads. In the US, the Greenroads rating scheme is a sustainability rating system for roadway design and construction. The tool assesses both mandatory practices (i.e. minimum requirements for green roads) and ‘voluntary credits’, which may be predefined or created through individual projects.[32]

5. What are the key strategic areas being investigated?

Strategic Area 1: Road construction aggregates

Road construction introduces huge quantities of foreign material to the natural environment and disrupts the soil conditions and runoff behavior for hundreds of kilometres. Consequently, the choice and use of road construction materials is important in reducing the environmental impact of roads. The environmental impact of road construction materials is governed by two major factors – the choice of materials and the processes through which those materials are used to construct the road. In general, the materials used for road construction affect the chemical composition of the surrounding environment (through the toxicity of leachate, runoff and groundwater), while the design and construction methods cause mechanical damage (erosion, soil disruption, watershed changes).

A major process involved in road construction is quarrying or 'extraction' of the source rock used to form the aggregates necessary for the sub-base, embankments, and in concrete and asphalt mixtures. This is done through drilling and blasting to reduce the rock mass to a particle size that can be dug from a loose rock.[33] This can be achieved through chemical means (explosives) or mechanical breakage. The extracted materials are then processed to make them appropriate for end use (as part of concrete or asphalt or in base layers). The requirements are defined in terms of particle size and distribution, shape and mechanical properties – for example, compressive strength. The process of crushing involves the continual reduction in size of the extracted material using either compaction or impact crushers. The aggregates produced are then tested to determine the relevant properties and transported (either wet or dry) to road construction sites or to plants to act as additives into concrete or asphalt, via road or rail.

(This area includes investigations into alternatives to extracted aggregates, performance of alternative materials, reducing toxins and contaminants, reducing energy in aggregate crushing, and recycled aggregate and crushed concrete.)

Strategic Area 2: Asphalt

The industrial asphalt used for road construction is refined from petroleum through a process of vacuum and steam refining. The asphalt is usually further processed through air blowing at elevated temperatures and is mixed with water to make it fluid for ease of placement. This emulsion process requires high temperatures (121ºC for the asphalt and ~50ºC for the water in traditional procedures).[34] The asphalt is shipped to an asphalt production facility and stored in large containers where it must be constantly heated to maintain fluidity. When an order for asphalt is received, aggregates of varying sizes are added to a mixer where the asphalt is injected as a fine spray. The mix is delivered to hot storage bins where it is kept until delivery to site.[35] The processes involved in the placement of modern roads include roadway preparation, excavation and stabilisation, base construction, the placement of asphalt or concrete in various ways, and finishing processes, such as line marking and maintenance. The removal of old roads requires both reclamation and disposal. The asphalt must be removed and reprocessed for recycling, which will involve crushing and reuse.

(This area includes investigations into asphalt aggregate alternatives, warm and semi-warm asphalt processes, cold asphalt processes, and reclaimed asphalt pavement.)

Strategic Area 3: Alternative cements

Innovative concrete products, such as Wagners Earth Friendly Concrete (EFC), normal concrete with an alternative sustainable binder, are leading the way in the use of more sustainable concrete. Current research and development trials undertaken through a licensing agreement with Zeobond have produced over 1,000 m^3 of retaining walls, street pavement, bridge beams and water tanks for commercial and private projects throughout Brisbane. The concrete exhibits better strength, shrinkage and acid resistance characteristics while saving over 150 kg of CO_2 per m^3.[36]

Strategic Area 4: Understanding future pressures on roads

In the coming decades, the design, construction and maintenance of roads will face a range of new, interconnected environmental, social and economic challenges. Environmental and carbon pressures will include the impacts of climate change on rainfall patterns and temperature profiles. Economic pressure will result from shifting global economic balances and flows, and will include materials and resources shortages, along with predicted increases in energy and resource prices globally.[37] Social pressures will include potential shifts to lighter vehicles, reduced use of cars because of higher fuel costs, and political pressure to respond to climate change and oil vulnerability.

Strategic Area 5: Consideration of existing and emerging frameworks

Existing efforts to adapt road-building practices to address the threats of climate change and oil issues are being enhanced by a number of emerging rating schemes and frameworks for infrastructure, in Australia and abroad. The research team is in the process of investigating a number of such schemes and tools – for instance, the Infrastructure Australia assessment process, the Australian Green Infrastructure Council[38] and its sustainability assessment tool with seven assessment categories, each category further subdivided into subcategories to make 28 assessment areas, as well as various state procurement processes and how they are adapting to include these questions.

(This area includes investigations into Australian Green Infrastructure Council (AGIC), VicRoads INVEST, Roads Australia, Infrastructure Australia, Greenroads (US), GAIA Environmental Assessment Tool, the Highway Sustainability Checklist, Institute for Sustainable Infrastructure, and Energy Conservation in Road Pavement Design.)

Strategic Area 6: Development of a *Carbon management guide for road agencies*

To streamline the consideration of carbon management within road agencies a guide will be developed to bring together the main steps in road planning, funding, procurement, delivery and maintenance. It will focus on the:

- road-planning processes (the four-step transport model used by consultants and governments to assess the need for roads and how to include carbon)
- road-funding assessment processes (Infrastructure Australia processes and their alignment in each state to see how carbon is assessed in strategic funding decisions)
- government agency road procurement processes (consideration of each state-specific process with partners and whether carbon can be included)
- road delivery processes (the AGIC system and how well it can include carbon)
- road maintenance processes (consideration of state-specific processes with partners in local government to see how carbon can be managed at this stage).

The emphasis will be on the need for carbon management practices to be incorporated into the various stages, and the research will lead to a guide to inform and help daily activities related to carbon management by road agencies.

Strategic Area 7: Understanding key trends and

scenarios set to affect the future of roads

In addition to the above strategic areas related to reducing the environmental pressure of roads and improving carbon management, the project will investigate potential trends and scenarios set to affect the future of roads.

Trends being considered include:

- increase in extreme weather events
- trips by walking, cycling and public transport increase
- resource shortages: aggregate shortages, fresh water scarcity, oil shortage
- road space distribution changes, with priority given to delivery vehicles within urban areas
- increase in the cost of road maintenance and construction
- oil-based road resurfacing made unfeasible due to oil scarcity.

6. The focus of the 'Future of Roads' project

Given the strong university, industry and government collaborative nature of the SBEnrc, the project has initially focused on preparing for and undertaking a range of stakeholder engagement activities to inform its outcomes. Building on this the project is being developed in three key areas: reducing the environmental pressures of roads; the management of carbon throughout the planning, funding, procurement, delivery and maintenance processes; and consideration of a range of trends and scenarios for the future of roads. The investigation is taking the following specific steps:

- Literature review. A comprehensive literature review was done by the research team to produce a summary of findings of over 28,000 words that was then refined to produce a 54-page summary. The literature review provides a valuable overview of a number of strategic areas, which were used as the basis of the stakeholder engagement
- Stakeholder engagement. A series of stakeholder meetings have been held along with the facilitation of two stakeholder workshops involving over 25 participants, in Perth and Brisbane. Participants were asked to provide feedback on the progress of the research team to date through a facilitated process and to then co-create the framework considerations for the future. Participants were asked to review selected outcomes from the literature review related to reducing the environmental pressures from road building, and then asked to identify critical indicators for roads in the future based on a discussion of potential future considerations, risks and pressures. The final session focused on how scenarios might be developed to deliver tangible benefits to stakeholders
- Development of a carbon management guide for road agencies. Based on the findings of the literature review and stakeholder engagement, the proposed sustainability assessment framework was reconfigured to provide an overarching platform to streamline the consideration of carbon management within road agencies, covering the core existing tools and processes in each of the main steps in road planning, funding, procurement, delivery and maintenance
- Analysis of case studies. The team is focusing on the assessment of case studies, including the Tullamarine Calder Interchange and Mickleham Road Duplication in Victoria, the Cunningham Highway in Queensland, and the Great Eastern Highway – Roe Highway Interchange and Kooyong Road to Tonkin Highway in Western Australia
- Reports and recommendations. Each of the three key areas will produce a report that will focus on outlining the associated findings. This will include a report on current efforts to reduce the environmental pressures from roads; a carbon management guide for Australian road agencies; and a report on a series of future trends and potential scenarios. Each of the outcomes will be focused on providing value to partners and will continue to be developed in close collaboration with stakeholders.

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The Sustainable Built Environment National Research Centre (SBEnrc) is the successor to Australia's CRC for Construction Innovation. Established on 1 January 2010, the SBEnrc is a key research broker between industry, government and research organisations for the built environment industry.

The SBEnrc is continuing to build an enduring value-adding national research and development centre in sustainable infrastructure and building, with significant support from public and private partners around Australia and internationally.

Benefits from SBEnrc activities are realised through national, industry and firm-level competitive advantages; market premiums through engagement in the collaborative research and development process; and early adoption of SBEnrc outputs. The SBEnrc integrates research across the environmental, social and economic sustainability areas in programs titled Greening the Built Environment; Developing Innovation and Safety Cultures; and Driving Productivity through Procurement.

Among the SBEnrc's objectives is collaboration across organisational, state and national boundaries to develop a strong and enduring network of built environment research stakeholders and to build value-adding collaborative industry research teams.

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